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Simple Methodology for the Stochastic Independent Event Calculation of Air Traffic Conflicts

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Introduction

- FAA tasked with safe and efficient operation of NAS

- Today's NAS consists of complex collection of facilities, systems, equipment, procedures, and airports operated by thousands of people to provide safe and efficient flying environment

- U.S. has one of safest and most complex aviation systems in the World, handling more than 35,000 airline operations each day

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Introduction (cont.)

- U.S. airlines expect to carry twice as many passengers by 2015 as today
- Important step towards future is implementation of an Safety Management System (SMS), applicable to all FAA organizations that promote and approve changes that affect provision of ATC and navigation services
- When new CNS equipment is added, it is of interest to quantify likelihood of conflicts in case of loss of some or all CNS functions

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Introduction (cont.)

- Accomplished typically with use of simulation
- Often advantageous to make rapid or generalized calculation when considering different flight regimes or changes to NAS or addition of technology
- Probabilistic methodology developed for quickly and simply calculating conflict likelihoods using aircraft size and speed and airspace type; may show promise for use in other calculations:
  - system availability
  - airspace capacity
  - allowable aircraft speed
  - aircraft size determination
  - CNS equipment MTBF

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Literature Review

- JPDO called for capacity of air transportation system to increase by as much as a factor of 3 over next 20 years while increasing security, safety, and efficiency
- This extra capacity would alleviate future bottlenecks; JPDO acknowledges achieving significant capacity increases unlikely unless new approaches found to go beyond limitations of current system
- Not clear that airspace is capable of handling traffic at densities several times greater than today

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Literature Review (cont.)

- Andrews *et al*. present a preliminary analysis of ability of highly automated separation assurance system to tolerate general types of faults (e.g., computer outages)
- Special attention given to impact of severe failure in which all computer support is terminated within a defined region
- Growth and decay of risk during outage evaluated using fault tree methods
- Authors show when conflict-free plan covers region of outage, can be used to transition aircraft to regions where service still provided

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Literature Review (cont.)

- Paglioni *et al*. generate conflict scenarios to estimate performance of conflict probe by making use of recorded air traffic data
- Since data generally does not contain actual separation violations, track data is time shifted to create traffic scenarios featuring conflicts
- Distributions obtained for several properties (e.g., encounter angle) that are most likely to affect the performance of a conflict probe
- GA utilized to determine values of time shifts for the recorded track data using Memphis Air Route Traffic Control Center

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Literature Review (cont.)

- Simulation used to model terminal portions of NAS as M/M/1/3 and M/M/2/6 queuing systems (Markovian arrival and service, i.e., exponential distribution; 1/2 servers, i.e., runways/helipads; 3/6 customers, i.e., A/C)

- 2 queuing systems (single runway and combination runway and helipad or two runways); different service rates used for different types of A/C

- Problem further complicated by servers each having 2 components to their service rate: time on approach (A/C speed-dependent) and time from touchdown to clearing runway (A/C maneuverability-and deceleration-dependent), each of which varies between A/C types

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Literature Review (cont.)

- Blom *et al*. outlines probabilistic risk assessment methodology developed for application to air traffic management (ATM)
- Present risk assessment results using this approach for 2 en route streams of traffic flying in opposite directions within 2 conventional ATM concepts and within 2 airborne separation assurance-based concepts
- Results illustrate how methodology supports safety-based ATM design
- Additional relevant and contemporary studies can be found in Bilimoria and Zeitlin *et al*.

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Problem Considerations

- Probabilistic methodology considered for quickly and simply calculating conflict likelihoods using A/C size and speed along with airspace type

- Simplified formulae treat A/C locations as independent events and as being random

- Calculations performed here for modeling of more than one A/C occupying same airspace under loss of communication and/or surveillance requires several assumptions

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Problem Considerations (cont.)

- Assumptions include:
  - not only are A/C positions random, but also no pilot or ATC intervention (IMC, comm fail) or functional assisting technologies (e.g., TCAS)
  - conflict avoidance not enabled through proper use of aircraft scheduling and routing, or other activities and technologies acting to prevent more than one A/C occupying same airspace

- Since these activities and technologies do exist in NAS, numbers calculated using methodology much higher than actual conflict probabilities

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Problem Considerations (cont.)

- Should only be calculated with this knowledge and only for use in making relative comparisons; e.g., how changing variables affect airspace congestion in relation to other possible changes or considerations

- Another assumption is all A/C stay precisely on planned route (e.g., airway or approach path); although should not necessarily be expected, simplifies calculations, though at cost of a further increase in value generated

- If not desired, methodology similar to bin approach but applied to vertical and horizontal planes in addition to the direction of flight could be applied

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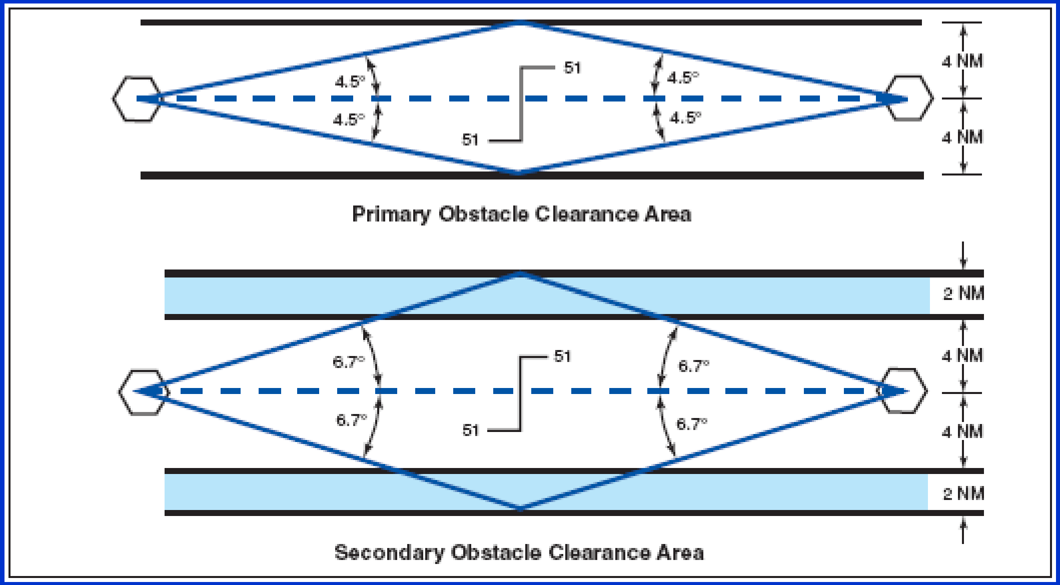
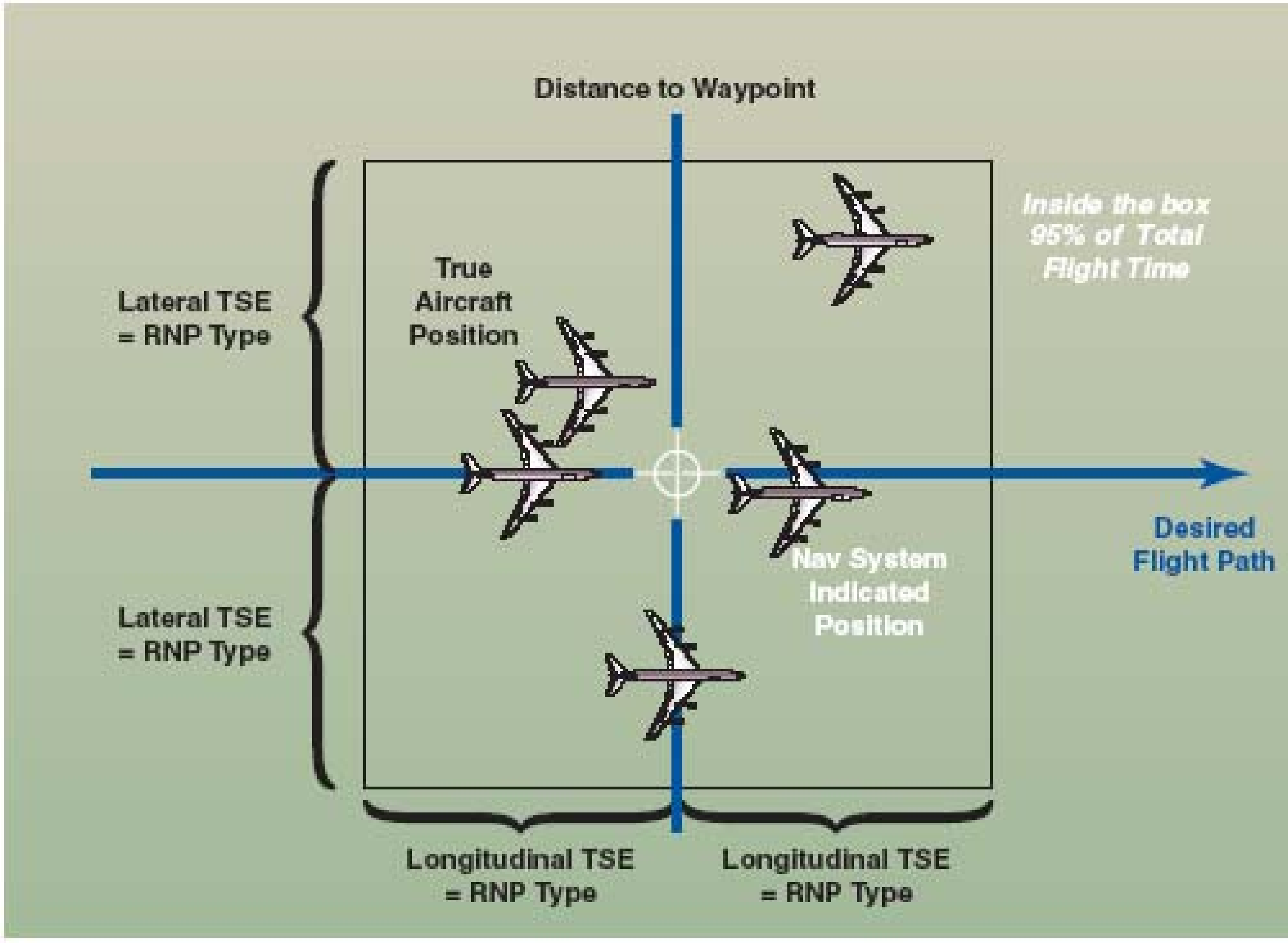
Airway distribution and size



ICAO required navigation performance



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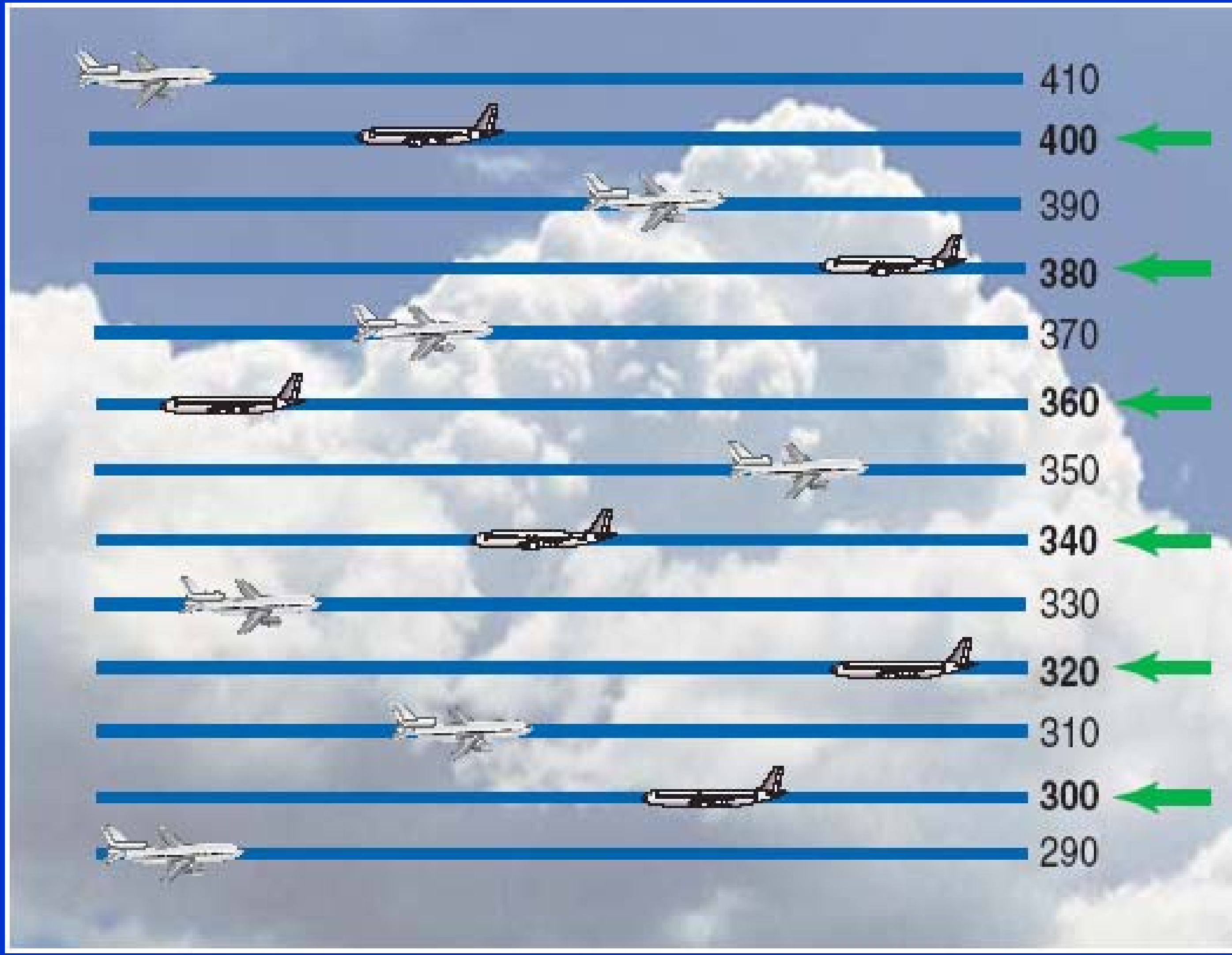
Reduced vertical separation



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Probabilistic Model

- Simulation requires specialized software or software development and typically does not lend itself to rapid study of a variety of problems in a short period
- NAS modeled using tools from field of probability; considers different airspace in NAS as routes and breaks up routes into bins size of 2 A/C lengths
- Predicated on A/C constantly in motion from current position to next, so conflict possible not only when 2 A/C occupy same space, but also during time A/C is clearing current position

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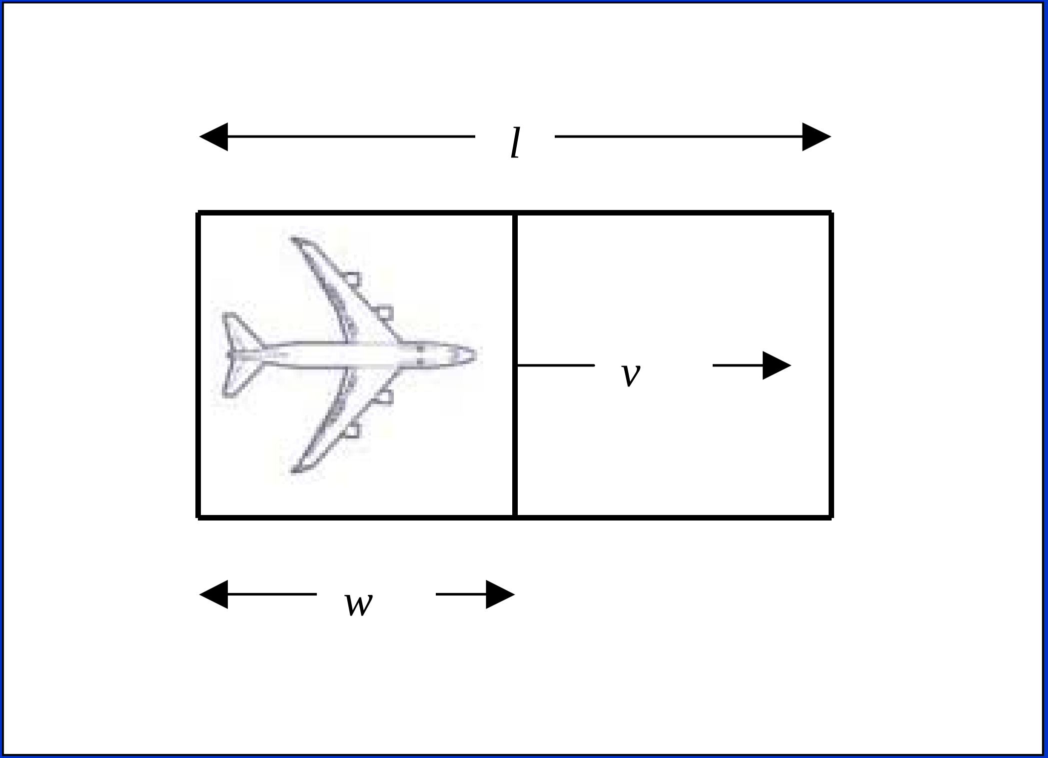
Probabilistic Model (cont.)



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Probabilistic Model (cont.)

- Until A/C travels length, 2 equally sized A/C in overlapping areas (defined by circle diameter of their length or wingspan, whichever is greater – typically length in modern “square” aircraft design), necessitating bin size of twice A/C’s length
- Number of alts (equal probability of assignment) in airspace under consideration to be accounted for as well (in Class B and C airspace will typically be 1)
- Given A/C’s length (best case, worst case, average case – mean, median, or mode) bin size is calculated

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Free flight concept protected areas

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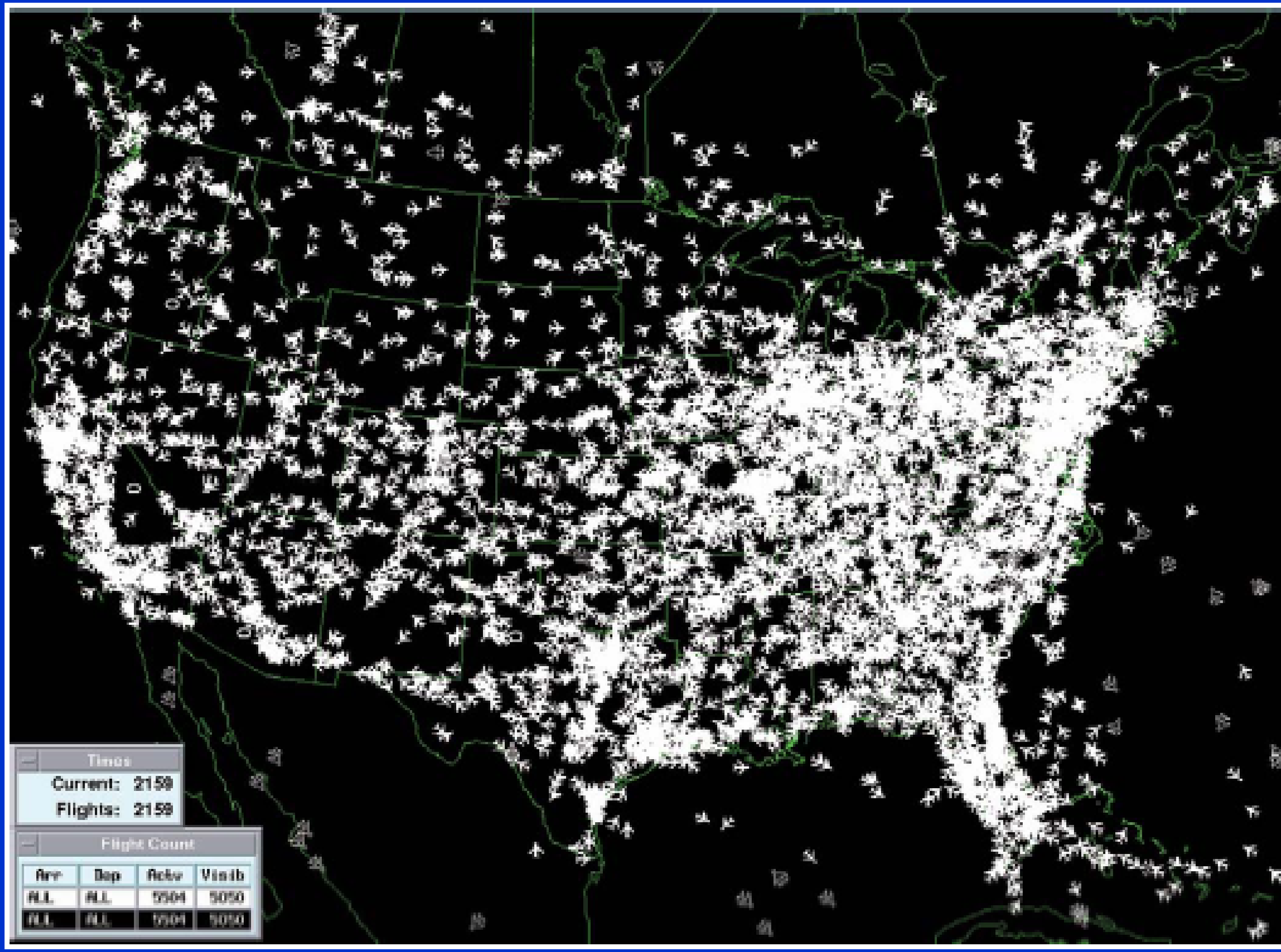
Aircraft distribution in the NAS



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Probabilistic Model Formulation

$$l = \frac{2w}{6{,}076}$$

$$b = \left\lfloor \frac{xy}{l} \right\rfloor$$

$$S = b^{a}$$

$${}_{b}P_{a} = \frac{b!}{(b-a)!}$$

$$P(1) = \frac{{}_{b}P_{a}}{S}$$

$$P(C) = 1 - P(1)$$

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Aircraft speed and size effects

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Probabilistic Model (cont.)

- Calculated values only effective during time A/C are in their bins
- Flying at a speed of *v* knots (either best case – slowest, worst case – fastest, or average case – using ceiling function of the mean, median, or mode), time *t* for an A/C to fly length of the bin can be calculated
- Since factorials grow extremely quickly and can easily reach computing limits of many modern systems, one of the methods that can be used is application of Stirling’s approximation

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Time Equations and Stirling's approximation

$$t = \frac{3{,}600l}{2v} \qquad k = \left\lceil \frac{3{,}600r}{t} \right\rceil$$

$$P(C) = 1 - (P(1))^k$$

$$\ln(n!) \cong n \cdot \ln(n) - n$$

$$\ln(b!) \cong b \cdot \ln(b) - b$$

$$\ln((b-a)!) \cong (b-a) \cdot \ln(b-a) - (b-a)$$

$${}_bP_a \cong e^{(b\cdot\ln(b)-b)-((b-a)\cdot\ln(b-a)-(b-a))}$$

Conclusions

- Probabilistic methodology presented for quickly and simply calculating conflict likelihoods under loss of communication and/or surveillance using A/C size/speed and airspace; formulae treat A/C locations as independent random events

- May be useful for other calculations:
  - system availability
  - airspace capacity
  - allowable A/C speed determination
  - allowable A/C size determination
  - CNS MTBF

- Formulae developed as a proof-of-concept and to initiate further research

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